Simulation Models for Sustainability

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The Concept of Sustainability

Sustainability is a property of a socio-economic system in the context of its physical environment. It is a property that applies to a system as whole. Just as 'temperature' and 'pressure' are properties that apply to a gas, not to the individual molecules that constitute the gas, sustainability is a property of the global ecosystem, not its constituent processes. Consequently sustainability can only be understood within the context of a theory or a conceptual framework that represents the main elements of the entire system.

A serious difficulty arises because the socio-economic system to which we wish to apply the concept of sustainability is characterized by complexity. Its constituent elements are both human activities and naturally occurring environmental processes; each process has its own time dynamic and is linked to other processes through a network of flows of materials and energy. To the extent that administration and governance systems isolate the constituent elements through jurisdictional issues, the network of material and energy flows is obscured.

Furthermore aggregation over space and time tends to obscure the relationships among the components of the system. Obviously a reductionist approach to the problem would be a contradiction; yet representing the component processes of the entire system is difficult both from the side of human activities and physical processes. A major constraint from the social sciences is that the conventional analytical tools used by them are not powerful enough to approach a problem of this magnitude. Although the analytic tools used by the physical sciences are more robust, science rarely operates with a full understanding of either the underlying processes or the context that influences them.

Sustainability is a concept that implicitly includes a time dynamic; namely it applies to the trajectory of a system. In order to determine whether a socio-economic system has the property of sustainability, it is necessary to examine its future evolution path. However, the future evolution path will in part result from human activities that are subject to choices that will be made in the future. Therefore, it is necessary to examine possible evolution paths that are contingent upon societal choices. Only a subset of the possible evolution paths are sustainable. (Hopefully the subset is not null.)

All of this means that risk and uncertainty must be faced directly, and the objective of the simulation system is to determine what choices must be made in order to yield a system that is sustainable.

User as Designer

Simulation models generally represent a set of processes that may be empirically quantified and/or simply parameterized based on principles or logic. The models are run with a set of initial conditions and a user specified policy scenario. These are applied to the processes so that the model projects values for several indicators for the duration of the run period. In order to explore alternative scenarios the user runs the model again with different policy settings or different assumptions. In effect the model tells the user "if you do this combination of things, the projection of the future will be thus." The user remains external to the model.

The design approach to modeling uses a different approach that explicitly incorporates the user in a series of scenario design considerations. As the user interacts with the model, the model immediately shows the user if some aspects of the future choices are untenable. In effect the model tells the user "If you do this, you will generate a shortfall in that; so better amend what you are choosing to do."

As in other modeling approaches, processes in the design approach to modeling are empirically quantified and/or based on logic. The user is shown a calibrated historical trend of variables, including those controlled by policy such as wood harvesting intensity or energy efficiency research. Based on these, and considerations about how fast policies can be changed, the user is asked to provide a future trajectory of policy variables. If there is not enough energy, material, or labour to realize a policy, then the user is given the opportunity to amend that policy, or to change other policies that depend on the same network of resources.

This process reflects the normal situation where different agencies and institutions independently set policies for those issues that they are responsible for within their sector with little awareness of what the implications of these policies are to other sectors. Similarly they do this without knowing how the policies in other sectors will influence the feasibility of what they plan. The GSS simulation system keeps track of these interactions, but does not try to generate a "solution". The balancing of limits and tradeoffs is appropriately left to the humans who will live the consequences. It is because people design a suite of workable policies in interaction with the simulation model, this approach is known as the design approach.

An Application of General Systems Theory

The design approach applies concepts from general system theory to socio-economic decision analysis. Effective action arises from a decision process that meets three conditions, namely:

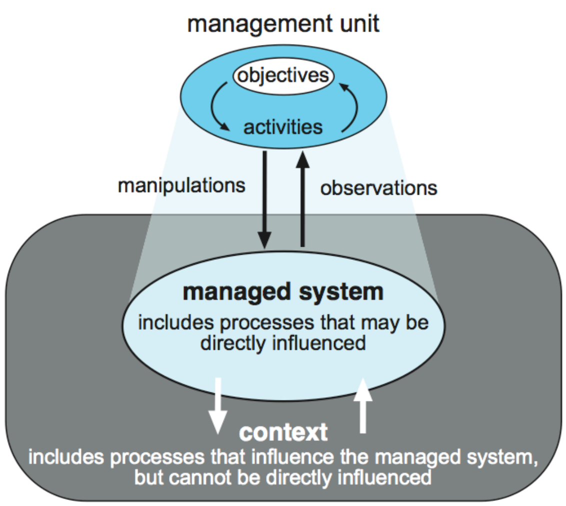
1) a well-defined objective, or, in a complex system, clarity concerning the acceptable range of values for various system attributes as well as a willingness to consider tradeoffs between conflicting objectives

2) an understanding of how the system in question works, including how it interacts with its environment

3) continuing observations of the state of the system that provide updates concerning the actual current state of the system to those who are taking actions within the system.

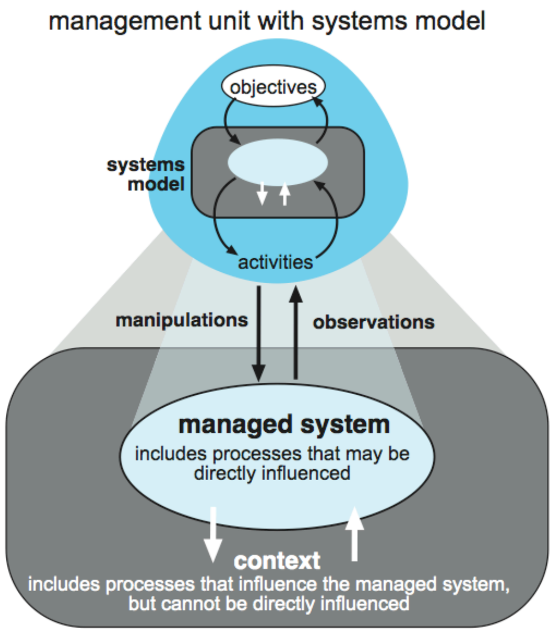
A responsible management unit will generally have specified their objectives, thus satisfying the first condition. The second condition, namely an adequate understanding of how the system works, is in fact a model of the system. The understanding may comprise an implicit or intuitive mental model, or it can be expressed explicitly as a systems model. A mental model may be entirely adequate where an expert has intimate and extensive experience with managing the whole system of concern. However, a mental model is a dynamic configuration within the expert's nervous system, and only limited aspects of it are verbal or mathematical, so it cannot be fully communicated to others. Furthermore where the system is too extensive or too complex, no individual can develop adequate expertise.

Another difficulty faced by a management unit is that there are always influences on the system that they manage that come from outside their management jurisdiction. Though these changes in the context may be observed they are often treated as "externalities." The influences of the context may be adapted to as they happen, or they may be proposed as different scenarios of influence and the management futures may be explored for alternative future conditions of the management context. However, this does not account for the interaction of the changes that result to the context from what the managed system does and how the context consequently influences the managed system. In other words, an understanding of how the system works has to take into account the network of interactions between the managed system and its context.



The third condition, adequate updates and awareness of actual system response is perhaps the most difficult condition to meet. Observations of the state of the system may be sporadic or they may be regularized in the form of an extensive monitoring program. However, in the absence of an understanding of the system dynamics it is very difficult to specify what to monitor, or to determine what the measures imply in terms of the system's response to the manipulations.

If the management unit includes an appropriate and adequately complex systems model both the second (understanding of the system) and third conditions (continuous updates) can be much more effectively met. An appropriate systems model not only represents the dynamics of the processes within the managed system that can be directly influenced, it also represents the reciprocal influences between the context or medium of the system and the system. Systems change over time, and hence a model is inadequate if it is incapable of representing only current conditions. The reciprocal influences between the system and its context should be adequately represented to account for changing configurations or conditions in either or both. This can be accomplished through including a systems model of the dynamic interactions between the managed system and its context as part of the management unit.



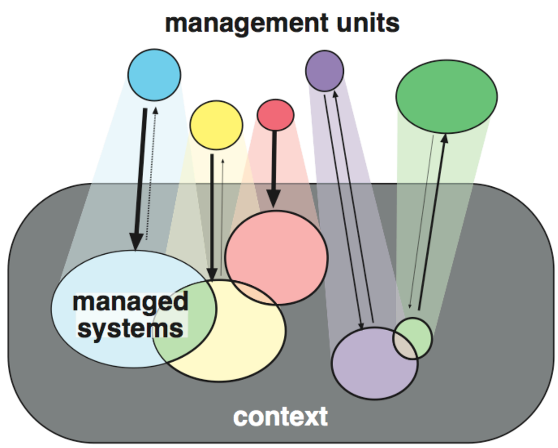
A further significant advantage of a systems model is that it helps to clarify what should be monitored to indicate the actual effectiveness of the manipulations performed on the system. This sometimes means that a parsimonious monitoring program can be used to determine the effectiveness of management actions.

The three conditions for effective management are addressed by many management approaches that incorporate systems models. For example, in the field of environmental management a substantive emphasis on the third condition (continuous updates) is known as Adaptive Management [Gunderson and Holling, 2004, Walters 1986.] In good adaptive management practice monitoring serves not only to provide feedback on the actual effectiveness of management actions, but is also used to continuously improve the systems model.

The Design Approach for Exploring Complex Objectives

In our modern institutionally based management culture the first condition of a set of workable well defined objectives is exceptionally difficult to achieve. Objectives are often specified by policy makers who do not have the opportunity to develop a good understanding of the dynamics of the system and its context, and thus the desired outcomes may simply be unachievable. This is particularly true in any complex system with multidimensional concerns. The objectives for different aspects of the system often conflict or interact so that achieving all of them is materially or energetically impossible. This means that the specified objectives for different elements are often unintentionally mutually contradictory.

Furthermore, in most complex situations different people or different agencies have jurisdiction over different parts of the whole context and thus work to achieve objectives that generate contradictions and conflicts among agencies.



In the above figure different management units with jurisdiction over different aspects of the overall system, or context, are show in different colors. Some units are small, and others large; and their size does not necessarily correspond with the extent of their management jurisdiction. As indicated in the figure by the varying line weights of the action arrows, some units have a strong management influence on their system, others are only able to nudge their system in minor ways. The actual jurisdiction of each managed system often overlaps with that of another unit, creating some degree of direct interaction between management actions. Such interactions are sometimes serendipitous, but more often they are problematic. In general management units are constitutively unaware of indirect influences on their management systems; the mechanisms for such awareness are generally beyond their budgetary constraints or their operating guidelines. Hence, although most units have some form of monitoring they are unable to distinguish the indirect influences that result from the activities of other agencies.

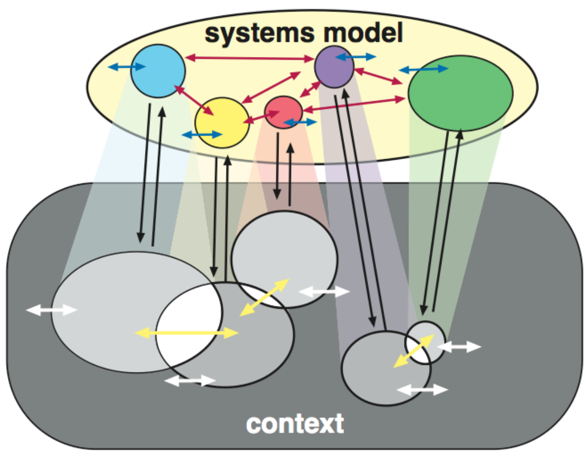
The design approach to systems modeling is particularly suited for dealing with this kind of situation. A design based rather than prediction based systems model supports the choice of objectives by facilitating the definition and exploration of alternatives.

The alternatives available through exploring a systems model are only valid if they take into account all the major influences on the system at the level of resolution that is represented. That is, the model, as a managing system, must incorporate as much complexity as the system that is being managed. In this context, it is worth recalling the cybernetic theorem, the Law of Requisite Variety, which states that regulator's capacity as a regulator cannot exceed its capacity as a channel of communication [Ashby, 1956.] In other words the regulator (or manager) can only be effective to the degree that he, she, or it is able to account for the complexity of the system to be regulated.

> *It comes down to this: we cannot regulate our interaction with any aspect of reality that our model of reality does not include - whether as to its theoretical range or as to its observational facilities and resolution - because we cannot by*

definition be conscious of it [Beer, 1980].

In the application of systems theory to managing for sustainability the 'manager' or controller is society itself: that is a collection of more or less interconnected individuals and institutions. Each individual or institution is responsible for managing some aspect of human activities, and is not responsible for other aspects. Consequently what one does, appropriate in their sector, may unintentionally undermine the management attempts in some other sector of activities. A systems model that includes these inter-relations provides a means for coordinating management activities across sectors. Ideally, all sectors will participate in the design activity of developing scenarios in a shared system that enables all sector managers to realize their responsibilities.



In the above figure the various management units are again shown in color. The indirect influences of the context on each jurisdiction (white arrows) are explicitly represented in the management model (blue arrows). When this is done properly the indirect consequences of the activities of any jurisdiction on the domain of another jurisdiction are made evident. These influences can then be considered in the designing of future scenarios through direct interaction between the units (red arrows). In the absence of actual conversation or negotiation between different agencies, a systems model that represents the systems managed by other agencies can allow a systems manager to take into account cross-sectoral dynamics. The direct influences between management activities in overlapping jurisdictions (yellow arrows) are similarly taken into consideration through the design of scenarios that resolve tradeoffs between the objectives and activities of different units.

The Global Simulation System and Sustainability

From the discussion above, it is clear that a conscious and explicit systems model plays a crucial role in developing and communicating a common understanding needed for effective interpretation of the observations and for both individual and collective action. The Global Simulation System is specifically designed to require the engagement of all users (or their proxies) that engage in the same management context. It is in their dynamic and collaborative design that realizable objectives and the activities to achieve these can be determined. Other simulation models do not require such engagement, and consequently cannot achieve the same results. Engagement does require time, and this is often difficult for management units to provide. (Managers tend to be rewarded for efficiency more than for effectiveness – perhaps in part because it is easier to measure the former)

As noted in the beginning of this essay, the property of sustainability cannot be directly observed or monitored because it is a property that applies to the future of the system. Not only is the future of the system not fully determined or indicated by its present state, but it is the result of a complex interplay between the activities of many different management units or agencies. Without an ability to account for indirect influences, no management unit can satisfy a mandate for sustainability.

The strategy adopted for the Global Simulation System (GSS) is to examine the property of sustainability in the context of an entire socio-economic system, but one whose components have been reduced to the minimum number required to illustrate linkages between ecological and economic processes. Minimizing the links allows the system to offer conceptual clarity at the cost of numerical accuracy. The pedagogic instantiation of GSS is a simplified model for familiarizing the user with basic concepts and fundamental constraints related to global sustainability. The methodology itself is capable of handling the compositional detail and the complexity of the relationships that would be required to improve quantitative accuracy that would be suitable for designing and implementing actual evolutionary paths towards global sustainability.